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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

IMPROVED PLANNING AND SHOP LOADING IN SHIPYARD PRODUCTION SHOPS

U.S. DEPARTMENT OF TRANSPORTATION
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FINAL REPORT

TASK EC-21

IMPROVED PLANNING AND SHOP LOADING IN SHIPYARD PRODUCTION SHOPS

Prepared by
Robinson-Page-McDonough and Associates, Inc.
Post Office Box 9
Greenland, New Hampshire 03840
(603) 436-7762

For
SNAME Ship Production Committee
Industrial Engineering Panel SP-8

Under The
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PREFACE

The National Shipbuilding Research Program is sponsored by the Maritime Administration, United States Department of Transportation, and by the United States Navy toward improving productivity in shipbuilding.

The Task reported herein investigates a way to improve planning and shop loading in shipyard production shops through use of scheduling standards, an approach first demonstrated during a pilot project at Peterson Builders, Inc. in 1982. A companion study at PBI that same year examined the statistical development of scheduling formulae, an alternate method for producing scheduling standards.

This Task investigates further the shipyard application of classification-level scheduling standard data transferred from another shipyard. It also treats in depth the process of developing scheduling standards from performance data using regression analysis. The prediction capability of each technique is tested against measured performance data.

The project was conducted by Rodney A. Robinson, Vice President of Robinson-Page-McDonough and Associates, Inc., assisted by Dr. Robert J. Graves, U. Mass., and Dr. Leon F. McGinnis, Georgia Tech. Participating shipyards were NASSCO, PBI, and Ingalls Shipbuilding Div. The Work began in May 1985 and was completed in September 1987.

EXECUTIVE SUMMARY

Planning and scheduling work in a shipyard production shop requires a **prediction** of how much **real time** will be consumed by a worker (or workers) in accomplishing a work package. On the surface this sounds fairly simple, and yet the process constitutes one of the more difficult tasks in shipbuilding because the **PREDICTION** element is so uncertain in practice. This Report discusses two ways to improve the quality of the prediction, which in turn will improve the usability of the planning and scheduling determinations.

The usual technique is to base the prediction of real time to do the work package on how long it took to do similar work in the past. This technique has three distinct shortcomings:

(1) The present work package **MAY NOT** have the exact same work content as the one selected from historical records to be the model;

(2) The labor collection system that yields the historical record **MAY NOT** have been sufficiently accurate and comprehensive to reflect the real time consumed on that work package; and

(3) There may have been **CHANGES** in shop conditions and work mix since the last performance, for which the historical performance approach is utterly unsensitive.

The need here is for a scientific approach that will more closely match the precise actions performed by the worker(s), and at the same time keep pace with changing conditions in the shipyard. Once the capability to make credible predictions is acquired, the process of planning and scheduling work becomes more reasonable, and can be extended to whatever bounds may suit the management style of the shipyard.

This Report examines **two new tools** that the planner/scheduler can use in making the vital prediction of real time to accomplish a work package.

(1) Scheduling standard data (either home-grown or imported) coupled with a current non-process factor unique to his shipyard; and

(2) A statistically-based prediction formula developed from current performance data measured in his own shipyard.

Each of these tools offers superior predictions compared to the techniques used in the past. Furthermore, each tool is self-improving through usage; that is, repeated usage will purify and improve each database as additional data are added to it. In the two shop areas investigated during this Task, sheet metal fabrication and pipe fabrication, **scheduling formulae were developed statistically which exhibited prediction errors of less than 10% of the observed work content in the test samples. Predictions based on imported classification-level standard data were in the range of 15%.** This represents strong evidence for the utility of these tools toward establishing credible predictions of real time to accomplish a work package, the quintessential ingredient for meaningful improvements in planning and shop loading in shipyard production shops.

These findings constitute the **third time** that these approaches have been demonstrated as being valuable for making work-package-level predictions of real time for accomplishment. It seems appropriate, therefore, to **strongly endorse the establishment within a shipyard of an ongoing, self-supporting system of scheduling standard development and application.** The system should include performance data collection and analysis, leading to the development of scheduling standards using regression analysis techniques. Concurrently, periodic work sampling should be carried out to allow the development of a non-process factor for use with classification-level scheduling standard data. Work sampling information will also reveal the true activities of the workforce, leading to improvements through reduction or elimination of useless efforts.

The use of either or both of these tools will enable substantial improvements in the quality and depth of planning and scheduling prescriptions, thereby generating major reductions in shipyard costs.

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REFERENCES

REFERENCE A - Bath Iron Works Corporation, Scheduling Standards Pilot Project Summary Report, May, 1982

REFERENCE B - Bath Iron Works Corporation, A Primer On An Approach To Planning And Scheduling For The Smaller Shipyard, December, 1983

REFERENCE C - Development of Scheduling Standards Using Regression Analysis: An Application Guide, Dr. Robert J. Graves, University of Massachusetts (Amherst) and Dr. Leon F. McGinnis, Georgia Technical Institute (Atlanta), June 30, 1987

FINAL REPORT

Task EC-21

Improved Planning and Shop Loading

in

Shipyard Production Shops

1.0 BACKGROUND

This Task was proposed on 16 July 1984 as an investigation into the area of improving shop scheduling and shop loading through use of scheduling standards (defined in Appendix A) which recognize work parameters (e.g., pipe material, diameter, number of joints, number of bends), work mix, shop capacity, and available resources as a step toward achieving improvements in the shipyard processes of scheduling, planning, and loading work packages and workers to accomplish shop work.

The usual approach to shop scheduling and shop loading is based on accumulated historical data and the interpretations of experienced personnel. This current method is frequently insensitive to changes in shop conditions and work mix, and is unable to efficiently utilize available resources (manpower, material, facilities, and time) that may have changed substantially since the last contract for similar work on which the scheduling predictions are being based.

This Task was an attempt to identify and assess the value of alternative bases for scheduling predictions. Specifically, (1) the viability of transferring scheduling standard data developed in one shipyard for application in another shipyard, and (2) the development of statistically-based predictions of real time needed to accomplish shop work based on actual performance data gathered in a shipyard for application in that same shipyard. Associated with the latter objective, an APPLICATION GUIDE for developing scheduling standards using regression analysis was produced under this Task.

The Task was begun on 9 May 1985 and was completed on 10 September 1987.

2.0 OVERVIEW

The Proposal for this Task identified a Ten Point Program for this research. Although the specific shipyards and areas to be involved would change somewhat during performance of the Task, the essential intentions of the Proposal were carried out.

Briefly, in the first major thrust of this Task, scheduling standard data in the sheet metal shape fabrication area were obtained from NASSCO*; these scheduling standard data were transferred to and applied at PBI by the Project Team. Concurrently, statistically-based formula standards in this same area were developed from performance data gathered at PBI; predictions based on these formula were tested against subsequent actual performance data at PBI by the Project Team.

In the second major thrust of this Task, scheduling standard data in the pipe fabrication area were obtained from PBI; these scheduling standard data were transferred to and applied at ISD by ISD. Concurrently, statistically-based formula standards in this same area were developed from performance data gathered at ISD; predictions based on these formula were tested against subsequent actual performance data at ISD by the Project Team.

Results indicate the following:

1. Classification standards for pipe fabrication and for sheet metal fabrication can be transferred, although in some cases a statistical approach may be more favorable than simply applying a non-process factor for the using shipyard to the imported classification-level standard data.

2. Regression-based formulae standards for pipe fabrication and for sheet metal fabrication can be developed and are quite accurate for predicting work content, provided they are applied to a mix of work representing at least a manweek of labor.

* The original intention had been to obtain small parts fabrication data from BIW for transfer to PBI, but obtaining sheet metal shape fabrication data from NASSCO was a more desirable alternative as Task initiation was approached.

NASSCO = National Steel and Shipbuilding Company, San Diego, CA.
PBI = Peterson Builders Inc., Sturgeon Bay, WI
ISD = Ingalls Shipbuilding Division, Pascagoula, MS

3.0 GENERAL DISCUSSION OF THE PROGRAM

The Ten Point Program for this research was conducted essentially as planned. Each of the Ten Points, stated in the language of the Proposal, along with a commentary on actions taken for each Point, follows.

Subtask 0: Orient selected shipyard personnel with pertinent details of this Task.

Selected personnel were briefed at PBI and at ISD both before the Task was initiated and after the Task was completed.

Subtask 1: In the sheet metal shape fabrication area, examine means to convert detailed MOST standard data into classification-level data for scheduling standards use.

This work had already been completed by NASSCO personnel. Classification-level data was immediately available in usable form for application at PBI. These data were offered freely by NASSCO, and were obtained for use during this Task without any difficulty whatever. PBI and NASSCO personnel were already mutually familiar with the shop areas and equipment at each shipyard, a situation that greatly enhanced usage of these data at PBI.

Subtask 2: In the sheet metal fabrication area, design and develop formulae to yield scheduling standards from raw in-house performance data.

A data collection form was designed, based on an evaluation of a sample of ten typical sheet metal shapes. Factors deemed to be relevant to time estimation included shape, dimensions, material type and gauge, seam type, and joint type. Performance data from the PBI sheet metal shop were gathered through use of forms filled out by the workers themselves. These data were reduced by the Project Team into a Lotus worksheet format for the analyses which would follow.

The principal problem encountered during this subtask was the unfavorable work mix in the shop which prevented the collection of needed data. Circumstances beyond the control of the Project Team resulted in a predominance of installation work onboard ship, rather than fabrication work in the shop, for much of the time during which this Task was being conducted. This work mix (along with a similar condition at ISD as reported below) precluded data collection for extended periods of time and forced a six-month contract extension. Aside from a few incomplete data entries that forced rejection of several lines of data, no other problems were evident.

Data were collected during four separate periods. For the purpose of formula development, the first three data sets were combined, yielding a database with a total of 394 records covering twenty-one different shapes. There were only six shapes for which there were sufficient data (twenty-five records or more) to support analysis.

Each of the six shapes was analyzed separately. Where appropriate, the database for a shape was further broken down by material, gauge, etc., to allow development of more accurate predictions. Acceptable models were developed for five of the shapes, although in some cases the models apply only for a particular material type, or range of gauges. **The conclusion for this subtask is that regression analysis may be applied successfully in a sheet metal shop to describe fabrication times, i.e., statistically "good" models can be constructed.**

As a part of this Task, an APPLICATION GUIDE for developing scheduling standards using regression analysis was produced. The APPLICATION GUIDE (Reference C) is published separately from this Final Report, consistent with the different readership for this material.

Subtask 3: In the sheet metal fabrication area, design and develop formulae to yield scheduling standards from classification-level data.

This effort involved the development of a non-process factor (References A and B) for the sheet metal fabrication shop at PBI for use with the scheduling standard data from NASSCO (which was already deviod of NASSCO non-process times). A simple non-process factor was all that was needed, since the sheet metal shops at NASSCO and at PBI were determined to be quite similar in size and equipment, and so were comparable in work capability.

The non-process factor was based on data from work sampling conducted randomly, five minutes out of every hour, for about two weeks. Data gathering was straightforward and without difficulty. Data reduction was carried out on a personal computer with relative ease. Since the overall time frame of this Task was so long, two non-process factor determinations were made in sync with the periods of performance data collection in the PBI sheet metal shop.

The non-process factor was applied to the NASSCO standard data to produce predictions of fabrication time for the shapes of interest. This process was simple, and took only a few hours. All four of the data sets were utilized, although several lines of data could not be used because attributes required to match those of the NASSCO standard data were missing from some of the PBI data.

Subtask 4: In the sheet metal fabrication area, assess the ease of transferring existing detailed MOST standard data for use in developing scheduling standards.

Since the aggregation of detailed MOST data into classification-level data had already been accomplished by NASSCO personnel, this tedious effort was avoided. Once the detailed data was so aggregated, the transfer of these data at this scheduling standard level was simple. The NASSCO data was already free of NASSCO non-process times, and so the residue of standard data was immediately ready for transfer.

Subtask 5: In the sheet metal fabrication area, conduct shop load comparison tests to measure the effectiveness of scheduling standards produced by each technique.

Application of the predictions based on NASSCO standards tempered by the PBI non-process factor was straightforward, and proceeded without difficulty. The data from all four sampling periods were used. Results are discussed under DETAILED DESCRIPTION OF TASK below. **Generally, the overall prediction error for four manweeks of fabrication effort was 15%,** representing an improvement over the scheduling accuracy usually found in shipyards.

Data from the fourth sampling period were used to evaluate the statistically developed prediction formulae. Attributes for the sheet metal shapes in the sample were used with the formulae developed from the first three samples to compute predicted fabrication hours. The actual fabrication hours as recorded by the mechanics were compared to the predictions. In the fourth sampling period, there were only four shapes which could be estimated. There were no prediction equations for the other shapes produced during the period. Prediction accuracy was assessed on a piece part basis, a shape basis, and a shop basis.

Individual piece part predictions could vary by as much as 100% or more from the actual fabrication times. However, when aggregated by shape, the predictions ranged from 5% low to 32% high. Considering the shop as a whole, the predictions from the formulae were **well within 10% of the actual fabrication times.** The total workload in the test sample was 1635 minutes, or approximately 2/3 of a manweek. **The conclusion for the subtask is that when applied to a mix of shapes and a large amount of work (approximately a manweek), the formulae standards are quite effective for predicting work content.**

Subtask 6: In the pipe fabrication area, design and develop formulae to yield scheduling standards from raw in-house performance data.

Performance data from the pipe fabrication area at ISD were provided by ISD Industrial Engineering personnel. These times came ultimately from the hours charged to the work by the shop mechanics at several selected work stations. These data were accompanied by sketches showing the technical details of each fabrication, from which the specific attributes of interest were extracted. Although attempts were made to have the mechanics enter their own time on separate data sheets (as had been done successfully at PBI), this action was not achieved. The precise timeliness and accuracy of the performance data was, therefore, somewhat in doubt (as subsequent analyses would show). As with PBI, delays were encountered in obtaining sufficient data for meaningful analyses. These delays, along with similar delays encountered at PBI, forced a six-month contract extension. Several sets of data were produced at various intervals of time. As these data were received from ISD, each set was entered by the Project Team into a Lotus worksheet format for subsequent analyses.

There were 5 different sampling periods at ISD. The fifth sample was used to evaluate the scheduling formulae. The first four samples were combined to form the modelling database, even though there were substantial differences in the average times recorded in samples one and two with those in samples three and four. Because times were recorded for assemblies, there were only 133 usable records in the modelling database, covering six different material types.

Formula standards were developed for the following cases:

1. Copper-nickel, 90-10; diameters 3.00 - 6.00; 1-8 welds
2. Copper; diameters 2.00 - 6.00; fewer than 8 braze joints
3. Carbon steel; diameters 2.00 - 6.00; fewer than 8 welds
4. Aluminum; 4.00 diameter only; at least one weld
5. Copper-nickel, 70-30; 10.00 diameter only; at least one weld

In these cases, good regression models were obtained, confirming the results from the Scheduling Standards Pilot Project at PBI (Reference A), i.e., **regression analysis may be applied successfully for describing pipe fabrication times.** (See also the APPLICATION GUIDE for developing scheduling standards using regression analysis, Reference C).

Subtask 7: In the pipe fabrication area, assess the ease of transferring existing classification-level data for use in developing scheduling standards.

Classification-level data in the pipe fabrication area was immediately available at PBI, and was offered freely for application at ISD. These data were devoid of PBI non-process times, and so were transferrable to ISD without any difficulty whatsoever. These data were accompanied by explanatory information about the precise processes used at PBI during the various steps of fabrication. The transfer was simple and without problems.

Subtask 8: In the pipe fabrication area, design and develop formulae to yield scheduling standards from classification-level data.

This subtask required development of a non-process factor for the ISD pipe fabrication shop area where data were being gathered. Although ISD would not provide such a number for use with the PBI standard data, ISD did perform an internal analysis of PBI standards vs. ISD performance data. Unfortunately, the results of this study arrived too late for the Project Team to evaluate and include in this Final Report.

Subtask 9: In the pipe fabrication area, conduct shop load comparison tests to measure the effectiveness of scheduling standards produced by each technique.

Application of the PBI classification-level standard data was found to be straightforward. However, since a non-process factor from ISD was not available, no attempt was made by the Project Team to apply these imported standard data at ISD.

In the data sample used to test the statistically developed prediction formulae, there were twenty-six records representing four material types (there was no aluminum pipe). Only fourteen of the records were usable, since the others fell outside the limits for which the models had been developed. Attributes for the fourteen pipe details were used with the formulae developed from the modelling database to compute predicted fabrication times. The actual fabrication times reported by ISD were compared to the predictions, and prediction accuracy was assessed on a pipe detail basis, material basis, and shop basis.

On an individual pipe detail basis, the prediction errors ranged from 5.5% to 127%. When aggregated by material type, the errors ranged from 14% to 55%. However, **for the test sample as a whole, the prediction error was only 10%.** The total workload in the test sample was 3498 minutes, or approximately a manweek and a half. **The conclusion for the subtask is that when applied to a mix of material types and a large amount of work (approximately a manweek), the formulae standards are very effective for predicting work content.**

Subtask 10: Develop recommendations for future effort in this area.

Three recommendations for further effort in this area were generated, as more fully discussed in paragraph 5.2 below. Briefly, they are as follows:

A. Use regional one-or-two-day workshops to spread the information from this Task to interested shipyard personnel.

B. Arrange a system for performance data collection in support of future effort in this area.

C. Identify, develop, and distribute to interested shipyard personnel as much classification-level standard data as is economically feasible.

4.0 DETAILED DISCUSSION OF TASK

4.1 Classification-level Standard Data for Sheet Metal Shapes from NASSCO

Classification-level standard data for several sheet metal shapes were already developed at NASSCO, and were made available to the Project Team. (An illustrative sample of these data is contained in Appendix B.) This circumstance avoided the tedious process of having to develop such data from MOST or similar MTM labor standard data for use during this Task. These classification-level data were obtained without any difficulty whatsoever. They were already devoid of non-process times, and so were immediately ready for transfer to PBI. The sheet metal shops at NASSCO and PBI were determined to be essentially similar in size and equipment, and so the classification-level standard data was judged likely to be suitable for application at PBI.

Work sampling was conducted at PBI toward development of a non-process factor to be used in conjunction with the NASSCO classification-level data. Work sampling, performed by a member of the Industrial Engineering Staff at PBI, was done randomly, five minutes out of every hour, for about two weeks. Data gathering was straightforward and without difficulty. Data reduction was carried out on a personal computer, which eased the task considerably. Two non-process factor determinations were made in view of the extended time frame for production data collection.

The PBI non-process factor (consistent with the time frame during which the production data were collected) was readily applied to the classification-level NASSCO data by the Project Team. The resulting prediction of time to fabricate the shape of interest was easily made. (The testing of these predictions is discussed later in this Section).

4.2 Classification-level Standard Data for Pipe Fabrication from PBI

Classification-level standard data from the pipe fabrication area at PBI had already been developed by PBI, and was freely made available to the Project Team. (Illustrative sample in Appendix E). This avoided the need for the Project Team to develop such data from MOST data. These classification-level data were devoid of PBI non-process times, and were accompanied by explanatory information about the processes used at PBI during pipe fabrication, which appeared sufficiently similar to those at ISD that these classification-level data should be suitable for application at ISD.

Application of the PBI classification-level data into scheduling predictions at ISD required a non-process factor for the pipe fabrication area at ISD. The Project Team was unable to obtain such a non-process factor from ISD.

ISD did, however, perform an internal analysis of PBI classification-level standard data vs. ISD performance data. Unfortunately, this analysis arrived too late for the Project Team to be able to make a meaningful analysis of it for inclusion in this Final Report.

4.3 Performance Data Collection for Sheet Metal Shapes at PBI

Performance data was collected in the PBI sheet metal shop during four separate periods of time. A data collection form (included in Appendix C) was designed, based on a sample of ten typical sheet metal shapes. Other shapes were later added to suit the actual fabrications encountered at PBI. Factors deemed relevant to time estimation included shape, dimensions, material type and gauge, seam type, and joint type (see listing and coding arrangement contained in Appendix C). These data were entered on the forms by the workers themselves. These data were then reduced by the Project Team into a Lotus worksheet format for the analyses that would follow. An illustrative sample of the reduced data is included in Appendix C.

All four sets of data were used to evaluate the imported classification-level standard data. The first three sets were used for the modelling database for the statistically developed scheduling formulae, and the data from the fourth set were used to evaluate these scheduling formulae, as discussed below.

The most important problem that occurred during data collection was the unfavorable work mix in the shop, which favored installation work rather that fabrication of shapes. This situation precluded data collection for extended periods of time, and (along with a similar condition at ISD reported below) forced a six-month extension in the contract for this Task. Other that a few incomplete entries that forced rejection of some lines of data, no other problems were evident.

4.4 Performance Data Collection for Pipe Fabrication at ISD

Performance data for the pipe fabrication area at ISD was provided by ISD Industrial Engineering personnel. Project Team attempts to have the data recorded by the workers themselves were not realized. The times provided came ultimately from the hours charged to the work by the shop mechanics at several selected work stations. These data were accompanied by pipe detail sketches showing the technical information for each fabrication. The specific attributes of interest were extracted from the pipe details by the Project Team. (A listing of the attributes used is included in Appendix D.)

As with PBI, delays were encountered in obtaining sufficient data for meaningful analysis. These delays (with similar delays at PBI) forced a six-month extension in the contract for this Task. Five sets of data were provided at various intervals of time. As these data were received from ISD, each set was entered by the Project Team into a Lotus worksheet format for analysis. An illustrative sample of reduced data is contained in Appendix D.

The first four sets of data were combined to form the modelling database, even though the average times in samples one and two differed markedly from the average times in samples three and four. The Project Team was not able to resolve the reason for this condition. The data in the fifth set were used to evaluate the scheduling formulae, as discussed below.

4.5 Scheduling Formulae Development and Evaluation

4.5.1 General Approach

In both the PBI sheet metal shop and the ISD pipe fabrication shop, the same general procedures were followed, consisting of four steps:

1. Data screening - evaluation of the raw data to identify any suspicious records; follow-up with shipyard to verify or correct errors; eliminate data record if necessary.

2. Initial model building - examination of the data using a variety of statistical tools in an effort to identify the range of data over which models can be developed, the predictor variables to use with the model, and the mathematical form of the model.

3. Regression analysis - computing coefficients for the scheduling formulae, and analyzing the results with regard to outliers, goodness of fit, and alternative model forms.

4. Testing - applicaton of the scheduling formulae to work that was not contained in the database from which the coefficients were computed.

(Note: These procedures are discussed in the APPLICATION GUIDE for developing scheduling standards using regression analysis, Reference C, produced under this Task and distributed separately to the interested readership.)

A summary of the results for each shop is given below. In every case, a number of models were examined, but only those actually selected for testing are reported.

4.5.2 PBI Sheet Metal Fabrication

The sheet metal shop fabricates a range of sheet metal shapes; over the period of the Task, data were collected on twenty-one shapes. The requirements for data collection were determined from a preliminary analysis of the ten most frequently produced shapes. The data elements collected are illustrated in Appendix C. There were three data collection periods prior to testing the scheduling formulae. At the end of each period, the data were screened, and any suspected errors were communicated to the shop for reconciliation. Examples of suspected errors would include a diameter measurement recorded for a rectangular shape, missing dimensions for a rectangular shape, or an angle for a straight shape. After screening, the first three data sets were combined into a modelling database, which contained a total of 394 records. Table 1 presents the frequency distribution for shapes in the modelling database.

Table 1
Frequency Table for Shape - Sorted by Frequency
PBI Data (Sets 1, 2, and 3 combined)

Value	Frequency	Percent	Valid Percent	Cum Percent
5	108	27.4	27.4	27.4
2	55	14.0	14.0	41.4
1	43	10.9	10.9	52.3
8	38	9.6	9.6	61.9
6	38	9.6	9.6	71.5
9	28	7.1	7.1	78.6
10	18	4.6	4.6	83.2
3	14	3.6	3.6	86.8
15	13	3.3	3.3	90.1
16	9	2.3	2.3	92.4
18	7	1.8	1.8	94.2
4	4	1.0	1.0	95.2
12	3	0.8	0.8	96.0
20	3	0.8	0.8	96.8
7	3	0.8	0.8	97.6
11	2	0.5	0.5	98.1
13	2	0.5	0.5	98.6
14	2	0.5	0.5	99.1
17	2	0.5	0.5	99.6
19	1	0.3	0.3	99.9
21	1	0.3	0.3	100.2
Total	394	100.0	100.0	

Valid Cases 394 Missing Cases 0

Recognizing that for a given shape there are likely to be several factors affecting fabrication time, it was decided that the only shapes that would be analyzed were those having at least twenty-five records in the modelling database. As a result, there were only six shapes for which an effort was made to develop scheduling formulae, shapes 1, 2, 5, 6, 8, and 9.

In analyzing a given shape, the first step was to establish the boundaries of the modelling database. This was done by examining crosstabulations, such as the one presented in Table 2 for shape 2 (rectangular transformer). The crosstabulation reveals that the observations are not uniformly distributed across the predictor variables. In this particular case, for material 1 (galvanized steel), the observations are concentrated in gauges 18, 20, and 22. For material 2 (perforated aluminum), the observations are concentrated in gauges 20, 22, and 24.

Table 2
Crosstabulation of Gauge by Material
for Shape 2 (rectangular transition)

	Material	1	3	Row Total
Gauge	11	2		2
	16	1	2	3
	18	4		4
	20	6	9	15
	22	18	7	25
	24		2	2
Column Total		31	20	51
Percent		60.8	39.2	100.0

Number of Missing Observations = 4
Material 1 = galvanized steel
Material 3 = stainless steel

Because of the unfavorable distribution of observations, records for gauges 11, and 16 were deleted from the modelling database. To determine if the remaining imbalance between materials in the distribution across gauges is important, a means analysis was done. The results are displayed in Table 3, which indicates that there may be substantial differences between gauges for a given material and between materials for a given gauge. On this basis, it was determined that different predictor equations should be developed for each material type.

Table 3
Means Analysis for Shape 2 (rectangular transformer)

Summaries of Time by levels of Gauge and Material

Variable	Mean	Std Dev	Cases
For entire population	64.3913	62.1223	46
Gauge 18	200.0000	128.6468	4
Material 1	200.0000	128.6468	4
Gauge 20	48.6000	15.5187	15
Material 1	44.0000	21.0238	6
Material 3	51.6667	10.8972	9
Gauge 22	54.4000	40.4485	25
Material 1	53.0556	40.4438	18
Material 3	57.8571	43.4796	7
Gauge 24	36.5000	4.9497	2
Material 3	36.5000	4.9497	2

Total Cases = 50   Missing Cases = 4 or 8.0%

For material type 1 (galvanized steel), a two-variable plot was generated, showing time with total opening area, and is reproduced in Figure 1. There is no discernable trend in this plot, indicating that the most reasonable prediction would be simply the mean of the modelling database.

This is not the case for material type 3 (perforated aluminum), as illustrated in Figure 2, where there is a clear trend.

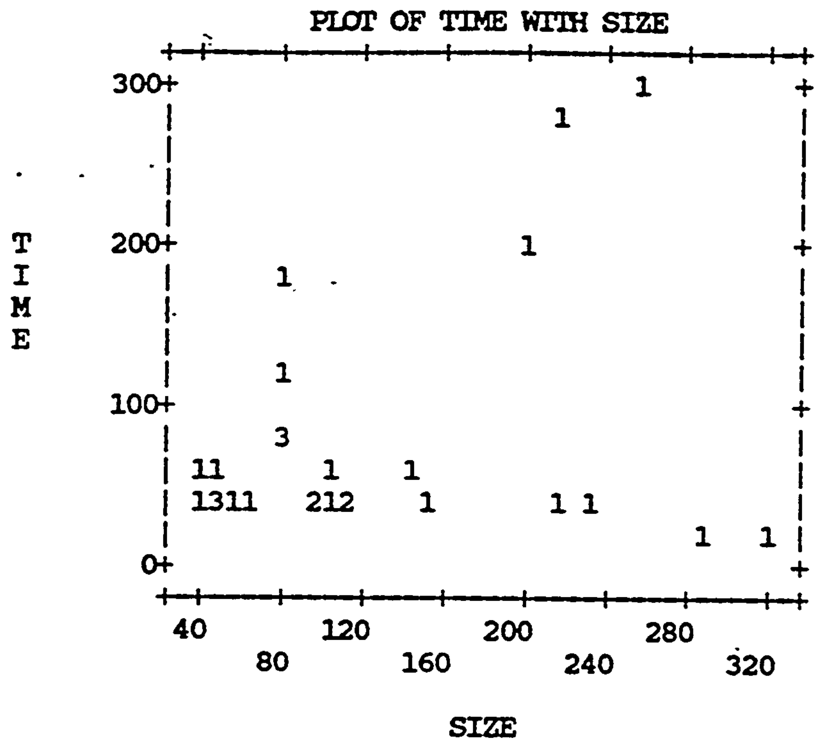


Figure 1
Time with Size for Material 1 (galv. steel), Shape 2 (rectangular transformer)

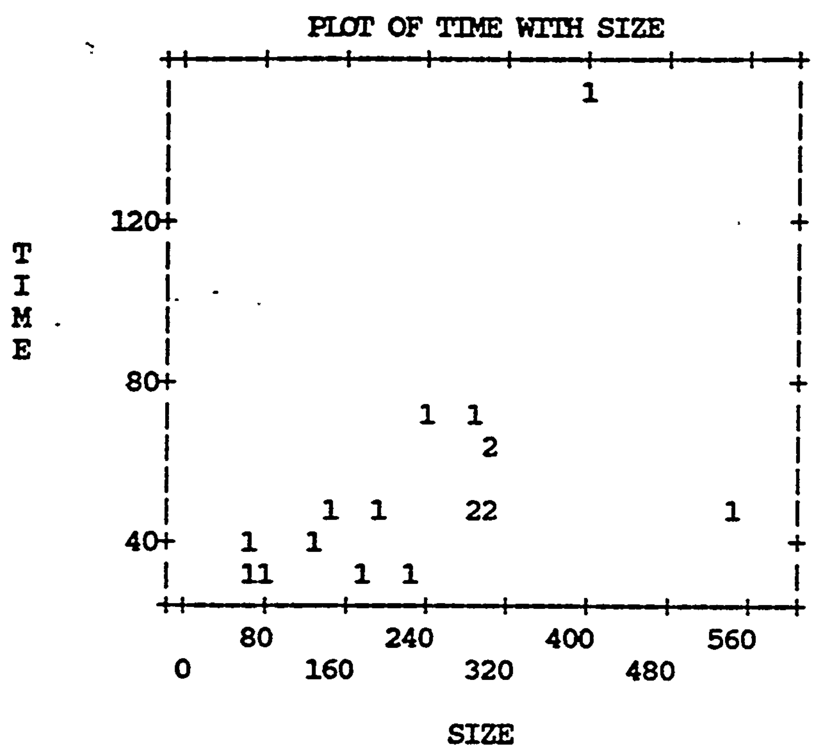


Figure 2
Time with Size, Material 3 (stainless steel), Shape 2 (rectanular transformer)

The subsequent regression analysis generated the prediction equation listed in Table 4. This same general analysis was repeated for each of the six shapes for which there were at least 25 records in the modelling database.

The scheduling formulae developed during the Task are summarized in Table 4. There is no formula for shape 9. Although there were 28 records for shape 9, there were only five unique records; i.e., there were five groups of records, and all records in a group were identical. The lack of variability in fabrication times for identical parts indicates potential problems in data collection. Even if the times are correct, there is not enough variation in part attributes to justify regression analysis for shape 9.

Table 4
Summary of Prediction Equations

Shape	Prediction Equation	Adj. R-sq	Mean	Std Error	No. Cases	Note
1	TIME = 1.15*(X1*Y1)	0.85	75.5	49.0	43	1
2	TIME = 0.33*(X1*Y1+X2*Y2)	0.59	76.3	73.8	55	1
	TIME = 0.43*(X1*Y1+X2*Y2)	0.64	91.7	84.7	31	2
	TIME = 0.20*(X1*Y1+X2*Y2)	0.82	54.8	27.1	20	3
5	TIME = 1.37*(X1+Y1) + 1.17*GAUGE	0.83	51.3	23.8	108	1
6	TIME = 0.70*GAUGE + 0.33*LEN1	0.85	26.3	11.0	38	1
8	TIME = 40 for GAUGE = 20, 22, 26 TIME = 60 for GAUGE = 24		52.3		38	1

NOTES:
1 - all observations for this shape
2 - only observations with material = 1 for this shape
3 - only observations with material = 3 for this shape
4 - only observations with GAUGE >= 20 for this shape
5 - only observations with material = 3 and joint $\neq$ 8 for this shape

Shape 1 = transition, rectangular to round
Shape 2 = rectangular transformer
Shape 5 = rectangular elbow
Shape 6 - straight duct
Shape 8 = offset
Material 1 = galvanized steel
Material 3 = stainless steel
Joint 8 = weld

The prediction equations were tested using the data from the fourth sampling period. Since there were no observations in the fourth set of data for shape 6, the corresponding prediction equation could not be tested. Details of the testing are presented below.

Testing model for Shape 1 - transition, rectangular to round

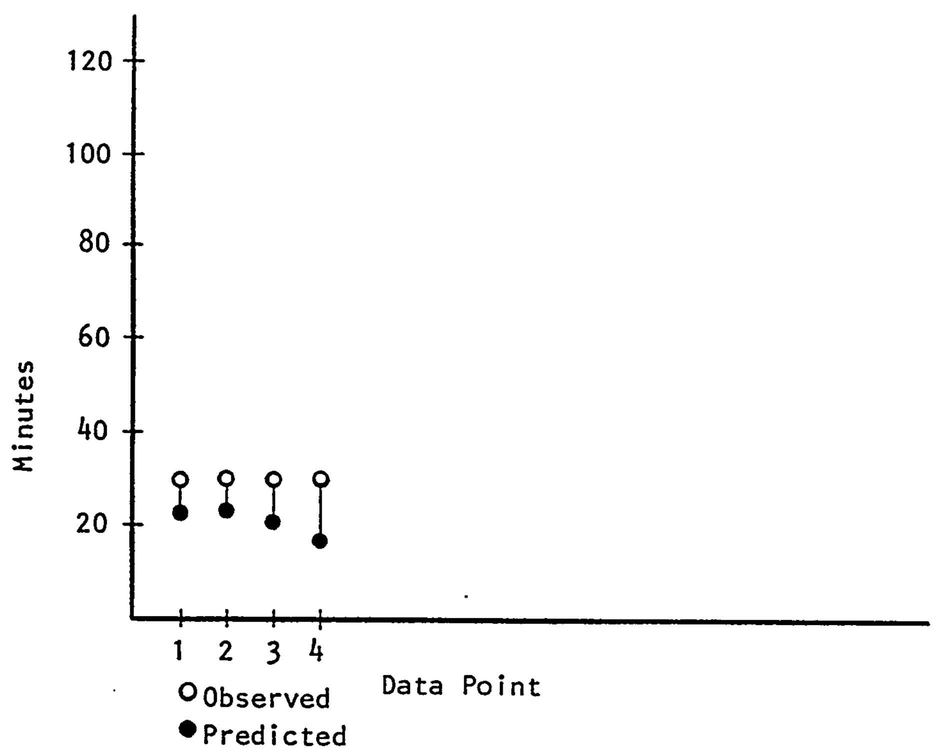
Time = 1.15*(X1*Y1)

N = 4 (4 of 5 records for shape 1 in PBI data set 4 are usable)

Adj. R-sq. = 0.85

Point	X1	Y1	TIME observed	TIME predicted	RESIDUAL
1	6.00	3.25	30.00	22.36	7.64
2	5.00	4.00	30.00	22.94	7.06
3	6.00	3.00	30.00	20.64	9.36
4	3.50	4.00	30.00	16.06	13.94
		TOTAL	120.00	82.00	

Prediction Error = 31.7%



Testing Model for Shape 2 - rectangular transformer
material type 3 (stainless steel)
joint type not 8 (weld)

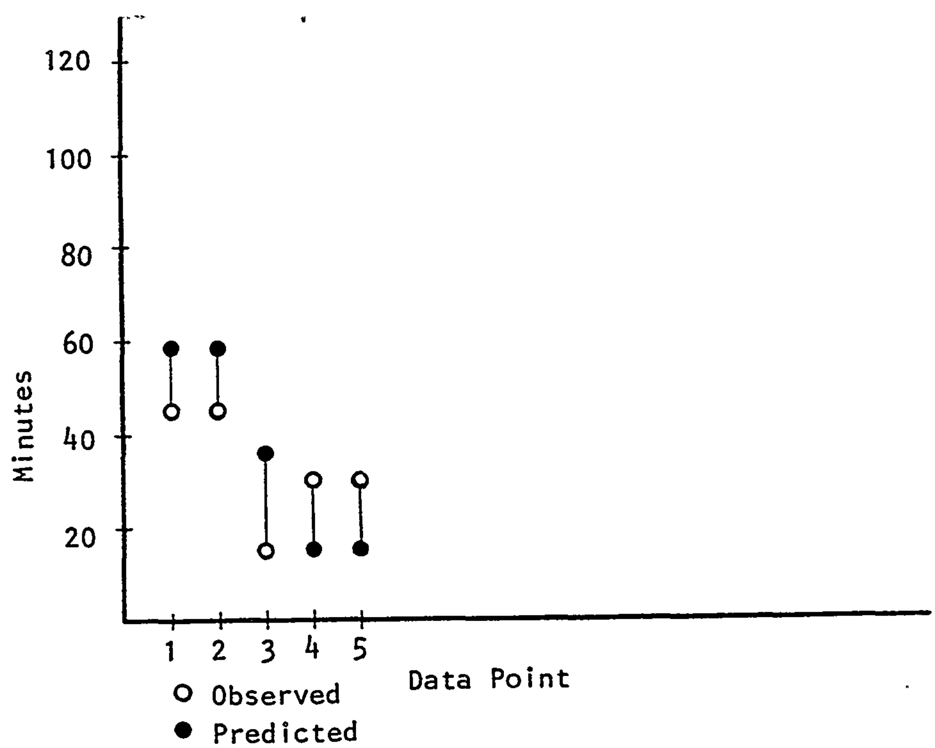
Time = 0.19*(X1*Y1+X2*Y2)

N = 5 (5 of 8 records for shape 2 in PBI data set 4 are usable)

Adj. R-sq. = 0.77

Point	X1	Y1	X2	Y2	TIME observed	TIME predicted	RESIDUAL
1	9.50	10.50	10.50	20.00	45.00	58.45	-13.45
2	9.50	10.50	10.50	20.00	45.00	58.45	-13.45
3	9.00	10.50	6.00	16.00	15.00	35.95	-20.95
4	4.00	9.50	4.00	10.50	30.00	15.10	14.90
5	4.00	9.50	4.00	10.50	30.00	15.10	14.90
				TOTAL	165.00	183.05	

Prediction Error = 11.0%



Testing Model for Shape 5 - rectangular elbow

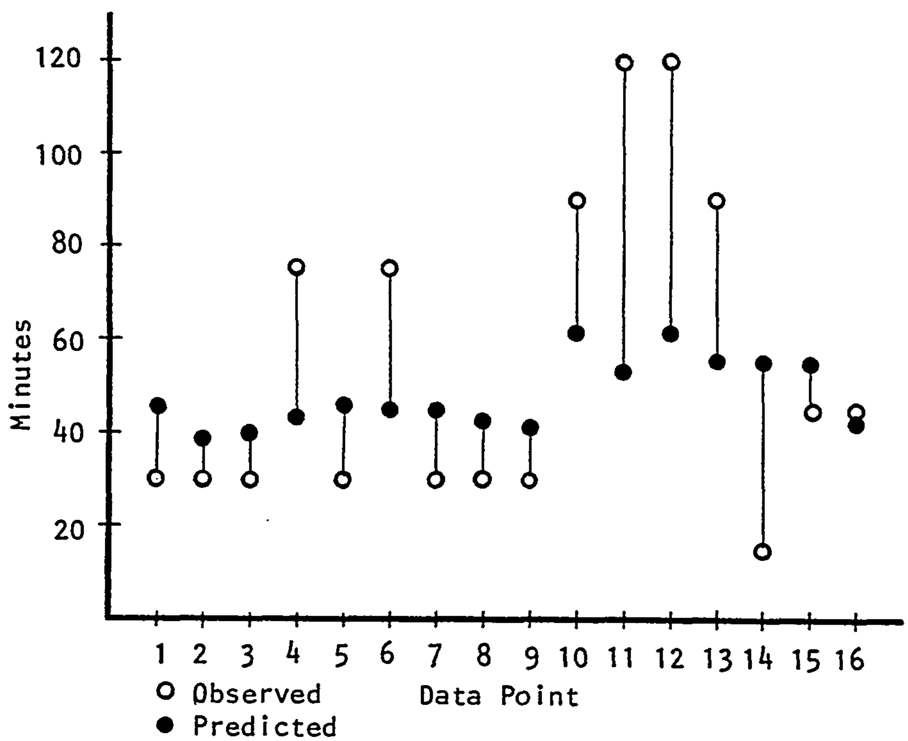
Time = 1.37*(X1+Y1) + 1.17*Gauge

N = 16 (16 of 17 records in PBI data set 4 are usable)

Adj. R-sq. = 0.83

Point	X1	Y1	GAUGE	TIME observed	TIME predicted	TIME RESIDUAL
1	4.00	7.00	26	30.00	45.49	-15.49
2	2.00	4.00	26	30.00	38.62	-8.62
3	3.00	4.00	26	30.00	39.99	-9.99
4	4.00	5.50	26	75.00	43.43	31.57
5	7.00	4.00	26	30.00	45.49	-15.49
6	4.00	6.50	26	75.00	44.80	30.20
7	4.00	6.50	26	30.00	44.80	-14.80
8	4.00	5.00	26	30.00	42.74	-12.74
9	4.00	4.00	26	30.00	41.37	-11.37
10	8.00	20.00	20	90.00	61.83	28.17
11	6.50	15.00	20	120.00	52.90	67.10
12	20.00	8.00	20	120.00	61.83	58.17
13	15.00	6.50	22	90.00	55.24	34.76
14	9.50	12.00	22	15.00	55.24	-40.24
15	9.50	12.00	22	45.00	55.24	-10.24
16	4.00	9.50	22	45.00	44.25	.75
			TOTAL	885.00	773.26	

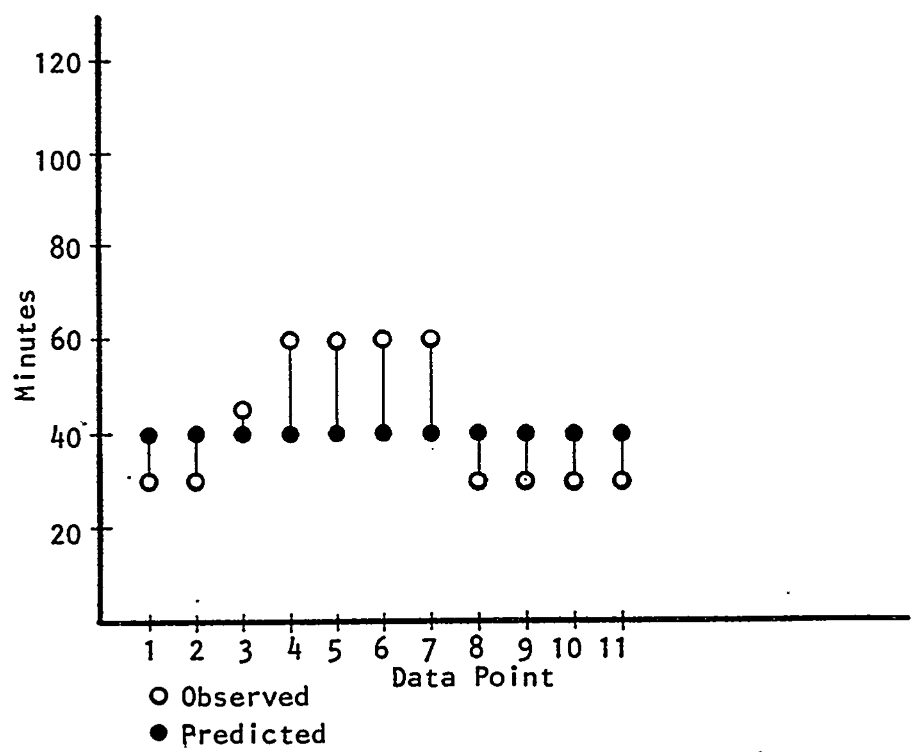
Prediction Error = 12.6%



Testing Model for Shape 8 - offset
Time = 40 (for gauge = 20, 22, 26)
Time = 60 (for gauge = 24
N = 11 (11 of 11 records for shape 8 in PBI data set 4 are usable)

Point	GAUGE	TIME observed	TIME predicted	RESIDUAL
1	26	30.00	40.00	-10.00
2	26	30.00	40.00	-10.00
3	22	45.00	40.00	5.00
4	22	60.00	40.00	20.00
5	22	60.00	40.00	20.00
6	22	60.00	40.00	20.00
7	22	60.00	40.00	20.00
8	22	30.00	40.00	-10.00
9	22	30.00	40.00	-10.00
10	22	30.00	40.00	-10.00
11	22	30.00	40.00	-10.00
	TOTAL	465.00	440.00	

Prediction Error = 5.4%



For the PBI sheet metal shop, the results of testing the predictor equations are summarized in Table 5. **For the total observed work content of 1635 minutes, the scheduling formulae predicted a workload of 1478 minutes, for a prediction error of 10%**

Table 5
Summary of Scheduling Formulae Testing

Shape	Observed	Predicted	% Error
1	120	82.00	31.7
2	165	183.05	10.9
5	885	773.26	12.6
8	465	440.00	5.4
Total	1635	1478.31	9.6

4.5.3 ISD Pipe Fabrication

The pipe shop at ISD fabricates pipe assemblies from a number of material types. The operations included in this analysis were welding, brazing, and mechanical joints, i.e., no sawing and no bending operations were considered. The data elements collected are illustrated in Appendix D. These are the attributes considered important in determining fabrication time from a scheduling formula.

There were four data collection periods prior to testing the scheduling formulae. The practice at ISD was to record a single time for an assembly, regardless of the number of spools, their material types, or their diameters. This type of record confounds the fabrication time with the assembly time. If there were a large number of records, it might be possible to develop scheduling formulae which combine fabrication and assembly. However, since the total number of records was relatively small (from a statistical analysis perspective), this was not possible. Therefore, the multiple line records (those with several spools but only one time value) were deleted from the modelling database. Subsequently, 26 additional records were deleted, due to erroneous data (invalid material, etc.) or because they were outliers (e.g., one record representing two manweeks of work, when the next largest was only two mandays).

The result of the data screening was a modelling database containing 133 records from four different sampling periods. Since the sampling periods were spread out over a significant period of time, there was some concern regarding the consistency in the data. Table 6 summarizes descriptive statistics for each of the four samples and for three different combinations of the four samples.

Table 6
Descriptive Statistics for ISD Data

Data Sets	Mean	Std. Dev.	Min	Max	N
1	289.17	154.83	54	768	77
2	166.30	92.88	42	456	42
3	2465.50	1945.28	649	5043	6
4	1358.13	746.55	605	2853	8
1+2	245.81	148.04	42	768	119
3+4	1832.71	1441.86	605	5043	14
1+2+3+4	412.85	680.67	42	5043	133

It seems clear from the data in the table that there were significant differences between the first two samples and the last two samples, since their means differ by almost an order of magnitude. Nevertheless, since there was no indicaton that this difference represented a structural change in the shop, all four data sets were combined in the modelling database.

Table 7 presents a means analysis of time by material for the ISD data, and indicates that there are significant effects due to material type. Based on the results in Table 7, it seems likely that different scheduling formulae would be required for each material type.

Table 7
Means Analysis of Time by Material

	Mean	Std Dev	Cases
For entire population	412.8496	680.6689	133
Material 0 (not specified)	238.0000	67.4398	3
Material 1 (copper-nickel 90-10)	415.3684	726.9904	57
Material 2 (copper)	211.5789	114.1375	19
Material 3 (cres)	1763.2000	1948.2122	5
Material 4 (carbon steel)	299.0000	282.2979	27
Material 5 (aluminum alloy)	412.6000	268.8999	10
Material 6 (copper-nickel 70-30)	457.0000	527.3664	12

Before analyzing the different material types in depth, crosstabulations were used to determine the range of attributes over which the scheduling formulae could safely be applied. Table 8 displays a crosstabulation of diameter by material. From the table it was clear that there was insufficient data to support analysis of material type 3. Also, for material types 5 and 6, only a single diameter could be analyzed. Finally, the analysis of material types 1, 2, and 4 would be valid only for limited ranges of diameter. These formulae limitations are summarized in Table 9.

Table 8
Crosstabulation of Diameter by Material

Dia	Material 0	1	2	3	4	5	6	Row Total
0.0	2							2
0.25			1					1
0.44			1					1
1.00		2		2				4
1.25		3						3
1.50		1			1			2
2.00		4	6	1	17	1	1	30
2.50		13	7	2	3			25
3.00	1	10	1		2	2		16
3.50		5	3		1			9
4.00	1	11			5	11		28
6.00		10	2		3			15
8.00		1			1			2
10.00		1					15	16
Total	4	61	21	5	33	14	16	154
Percent	2.6	39.6	13.6	3.2	21.4	9.1	10.4	100.0

Number of Missing Observations = 4

Table 9
Formula Limitations Based on Diameter

Material	Minimum Diameter	Maximum Diameter
1	1.00	6.00
2	2.00	3.50
4	2.00	6.00
5	4.00	4.00
6	10.00	10.00

Similar crosstabulations were run for number of welds, number of braze joints, and number of mechanical joints. In each case, the distribution of observations indicated that the scheduling formulae that might be developed should be limited in application to avoid the error of extrapolation. These limitations are summarized in Table 10. It is important to note that these limitations are due to the modelling database, and not to the basic method being used to develop the scheduling formulae.

Table 10
Formulae Limitation Based on Welds, Braze, and Mechanical Joints

Material	Maximum Welds	Maximum Braze	Maximum Mechanical
1	8	6	7
2	0	7	0
4	8	0	0
5	5	0	0
6	5	0	0

A total of seven different scheduling formulae were developed, and are summarized in Table 11. The first two apply across all material types, and were constructed simply as an experiment to see how accurate such a formula might be. Model 1 was based on the data from the first two sampling periods, while model 2 was based on the aggregate of all four sampling periods. It is instructive to note how much the "best" model changes when data from the last two periods are added to the analysis - another indication of the differences between the sampling periods.

The data from the fifth sampling period were used to test the scheduling formulae, provided they fell within the limits of application shown in Tables 9 and 10. Details of the testing are listed below.

Table 11
Scheduling Formulae from ISD Pipe Shop

No.	Prediction Equation	Data Sets	Adj. R-sq	Std. Error
1	TIME = 20.50*(Dia) + 49.44*(Wld) + 26.07*(Brz) + 53.15*(Mec)	1+2	0.86	109.17
2	TIME = 38.26*(Dia) + 11.27*(Wld)^2 + 2.67*(Brz)^2 + 43.85*(Mec)	1+2+3+4	0.88	279.83
3	TIME = 240.9*(Wld)	Note 1	0.97	214.90
4	TIME = 81.0*(Wld)	Note 2	0.79	125.40
5	TIME = 54.5*(Brz)	Note 3	0.86	86.50
6	TIME = 56.3*(Wld)	Note 4	0.81	112.50
7	TIME = 120.0*(Wld)	Note 5	0.85	121.00

NOTES: 1 - all records with material = 1, Dia <= 2.5, and Brz <= 9
2 - all records with material = 1, Dia >= 3.0, Wld <= 6, and Dia <= 6
3 - all records with material = 2, Dia >= 2.0, and Brz <= 7
4 - all records with material = 4, and Wld <= 7
5 - all records with material = 6, and Dia = 10

Material 1 = copper-nickel 90-10
Material 2 = copper
Material 4 = carbon steel
Material 6 = copper-nickel 70-30

Testing Model 1

Time (ATOT) = 20.50*(Dia) + 49.44*(Wld) + 26.07*(Brz) + 53.15*(Mec)

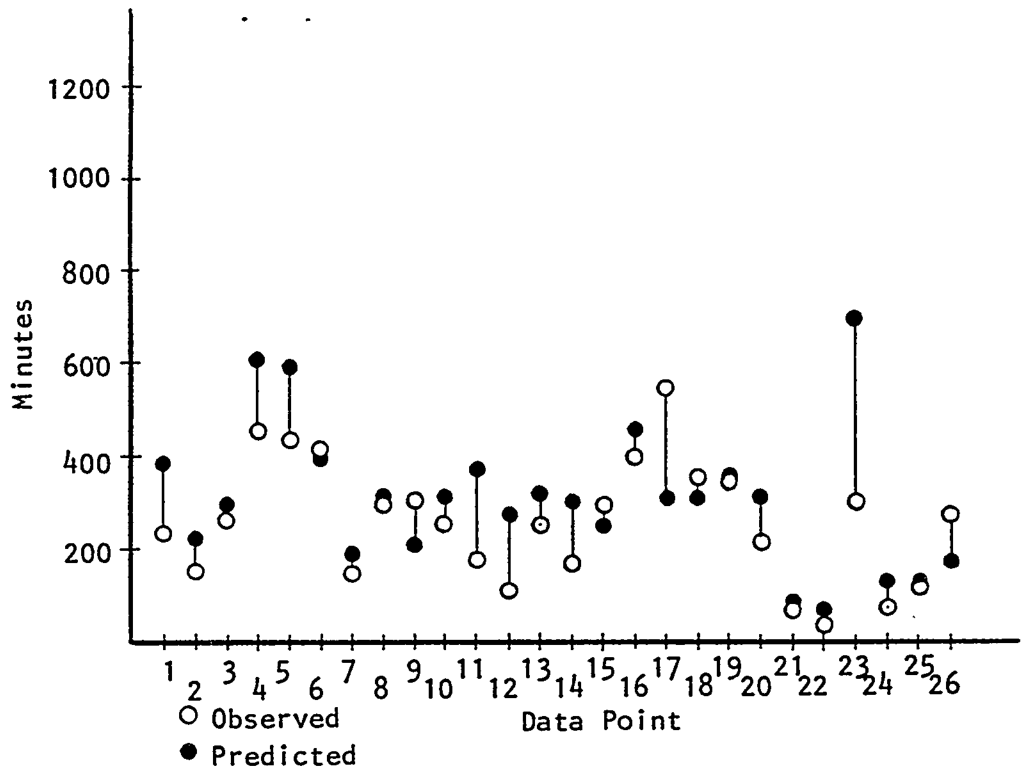
N = 26 (26 Of 26 records in ISD data set 5 are usable)

Adj. R-sq. = 0.86

					ATOT		
Point	DIA	WLD	BRZ	MEC	observed	predicted	RESIDUAL
1	2.00	7	0	0	235.00	387.10	-152.10
2	6.00	2	0	0	156.00	221.89	-65.89
3	4.00	0	8	0	267.00	290.52	-23.52
4	.50	2	19	0	459.00	604.38	-145.38
5	1.00	0	22	0	435.00	593.94	-158.94
6	1.50	0	10	2	415.00	397.71	17.29
7	2.00	3	0	0	148.00	189.33	-41.33
8	10.00	2	0	0	292.00	303.89	-11.89
9	2.50	0	6	0	304.00	207.64	96.36
10	3.50	5	0	0	259.00	318.96	-59.96
11	3.50	5	0	1	180.00	372.11	-192.11
12	3.50	3	0	1	107.00	273.23	-166.23
13	3.50	5	0	0	254.00	318.96	-64.96
14	2.00	0	10	0	168.00	301.66	-133.66
15	5.00	3	0	0	299.00	250.83	48.17
16	2.00	0	16	0	399.00	458.05	-59.05
17	10.00	2	0	0	544.00	303.89	240.11
18	10.00	2	0	0	354.00	303.89	50.11
19	10.00	3	0	0	347.00	353.33	-6.33
20	10.00	2	0	0	219.00	303.89	-84.89
21	3.00	0	1	0	64.00	87.57	-23.57
22	2.00	0	1	0	37.00	67.07	-30.07
23	2.50	3	11	4	300.00	698.90	-398.90
24	2.50	0	3	0	75.00	129.45	-54.45
25	2.50	0	3	0	116.00	129.45	-13.45
26	1.25	3	0	0	273.00	173.95	99.05
				TOTAL	6706.00	8041.59	

Prediction Error = 19.9%

*** Plot is on the next page ***



1200
1000
800
600
400
200
Minutes
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Data Point
Observed
Predicted

Testing Model 2

Time (ATOT) = 38.26*(Dia) + 11.27*(Wld)^2 + 2.67*(Brz)^2 + 43.85*(Mec)

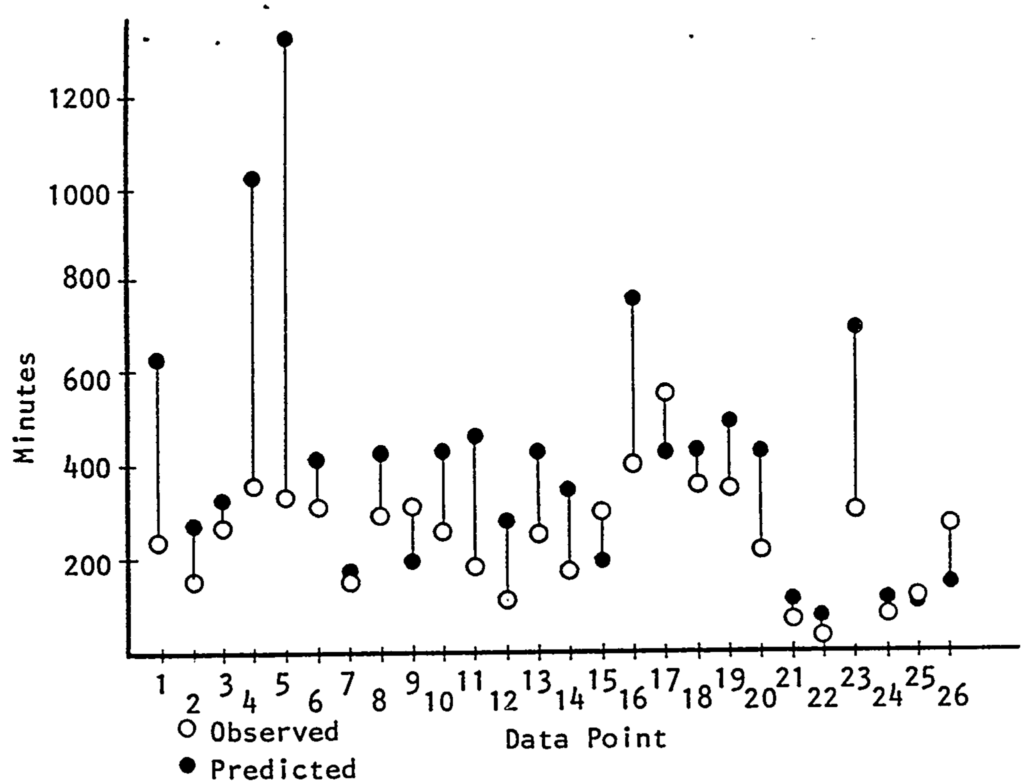
N = 26 (26 of 26 records in ISD data set 5 are usable)

Adj. R-sq. = 0.88

Point	DIA	WLD	BRZ	MEC	ATOT observed	ATOT predicted	RESIDUAL
1	2.00	7	0	0	235	628.96	-393.96
2	6.00	2	0	0	156	274.66	-118.66
3	4.00	0	8	0	267	323.87	-56.87
4	.50	2	19	0	459	1027.84	-568.84
5	1.00	0	22	0	435	1330.20	-895.20
6	1.50	0	10	2	415	412.01	2.99
7	2.00	3	0	0	148	177.99	-29.99
8	10.00	2	0	0	292	427.69	-135.69
9	2.50	0	6	0	304	191.74	112.26
10	3.50	5	0	0	259	415.77	-156.77
11	3.50	5	0	1	180	459.61	-279.61
12	3.50	3	0	1	107	279.22	-172.22
13	3.50	5	0	0	254	415.77	-161.77
14	2.00	0	10	0	168	343.45	-175.45
15	5.00	3	0	0	299	292.77	6.23
16	2.00	0	16	0	399	759.86	-360.86
17	10.00	2	0	0	544	427.69	116.31
18	10.00	2	0	0	354	427.69	-73.69
19	10.00	3	0	0	347	484.07	-137.07
20	10.00	2	0	0	219	427.69	-208.69
21	3.00	0	1	0	64	117.45	-53.45
22	2.00	0	1	0	37	79.19	-42.19
23	2.50	3	11	4	300	695.49	-395.49
24	2.50	0	3	0	75	119.67	-44.67
25	2.50	0	3	0	116	119.67	-3.67
26	1.25	3	0	0	273	149.29	123.71
				TOTAL	6706.00	10809.31	

Prediction Error = 61.2%

*** Plot is on the next page ***

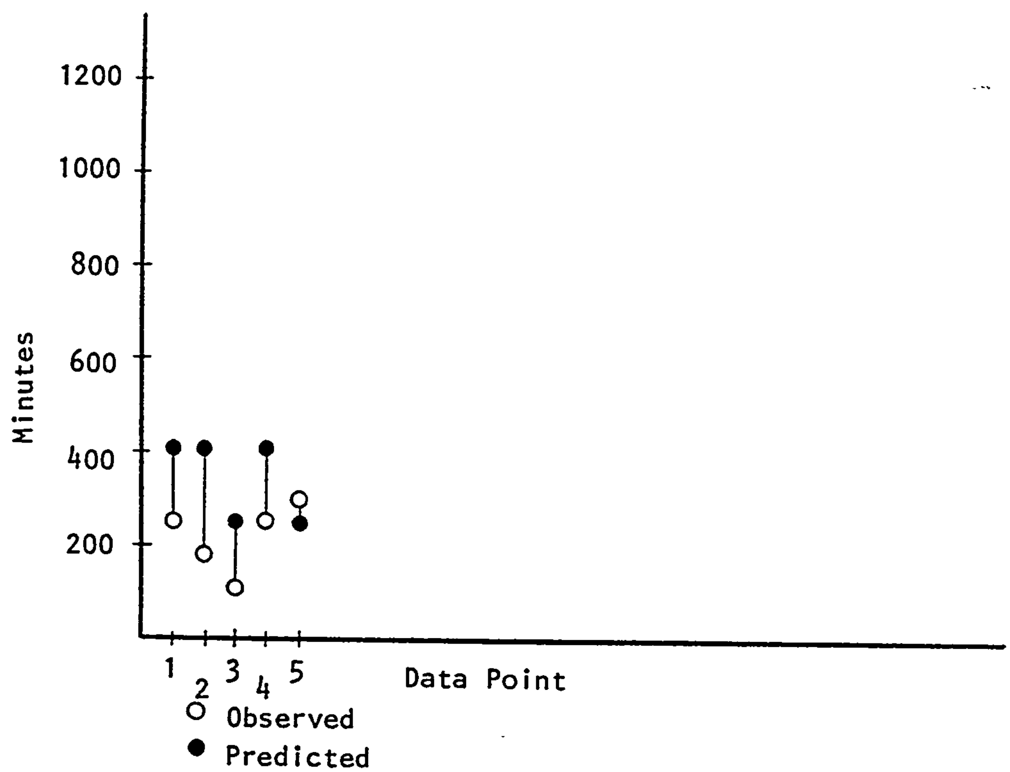


Model 3 is not tested because there are no matching records in ISD data set 5

Testing Model 4
Time (ATOT) = 81.0*(Wld)
N = 5 (5 of 11 records in ISD data set 5 are usable)
Adj. R-sq. = 0.79

Point	WLD	ATOT observed	ATOT predicted	RESIDUAL
1	5	259.00	405.00	-146.00
2	5	180.00	405.00	-225.00
3	3	107.00	243.00	-136.00
4	5	254.00	405.00	-151.00
5	3	299.00	243.00	56.00
	TOTAL	1099.00	1701.00	

Prediction Error = 54.8%



Testing Model 5

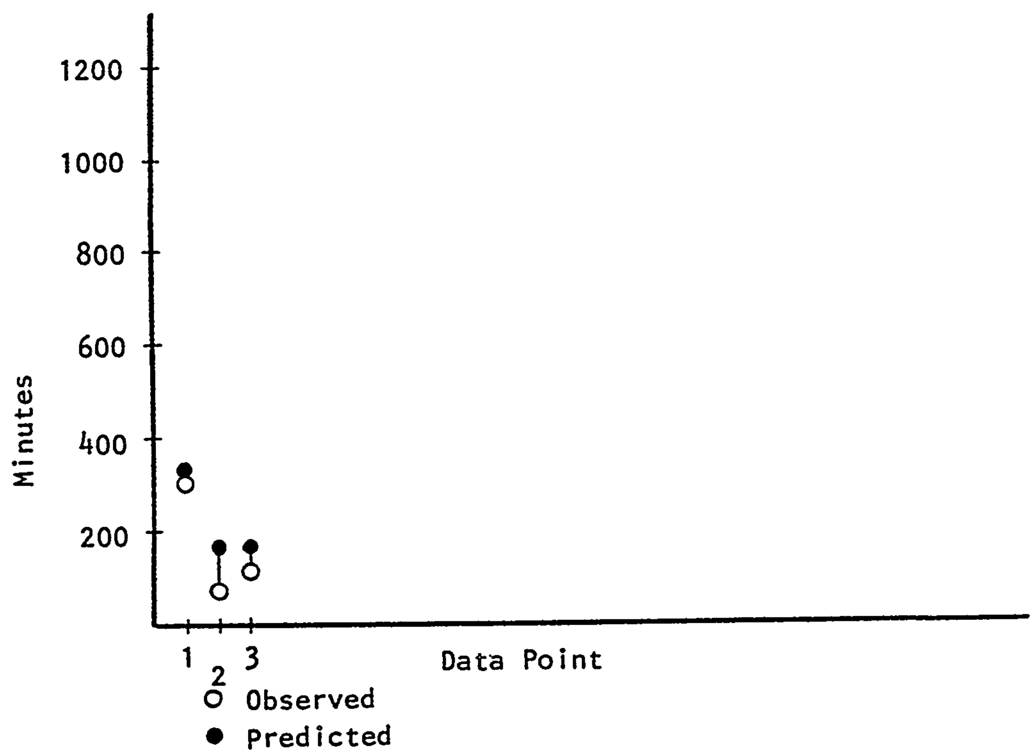
Time (ATOT) = 54.5*(Brz)

N = 3 (3 of 5 records in ISD data set 5 are usable)

Adj. R-sq. = 0.86

Point	BRZ	ATOT observed	ATOT predicted	RESIDUAL
1	6	304.00	327.00	-23.00
2	3	75.00	163.50	-88.50
3	3	116.00	163.50	-47.50
	TOTAL	495.00	653.00	

Prediction Error = 31.9%



Testing Model 6

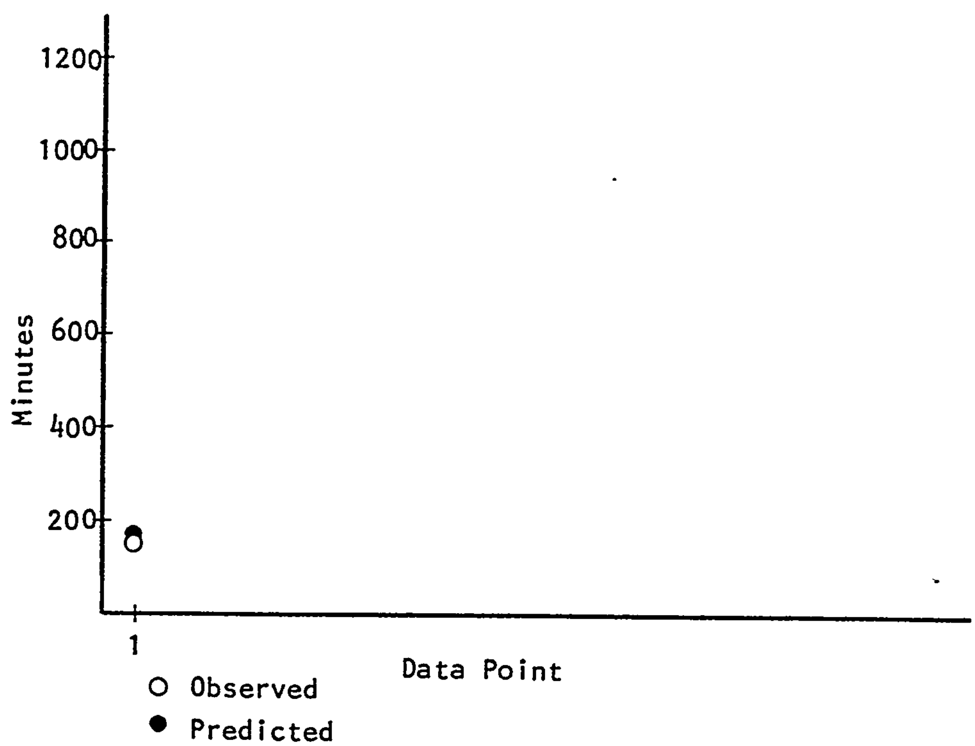
Time (ATOT) = 56.3*(Wld)

N = 1 (1 of 1 record in ISD data set 5 was usable)

Adj. R-sq. = 0.81

Point	WLD	ATOT observed	ATOT predicted	RESIDUAL
1	3	148.00	168.90	-20.90

Prediction Error = 14.1%



Testing Model 7

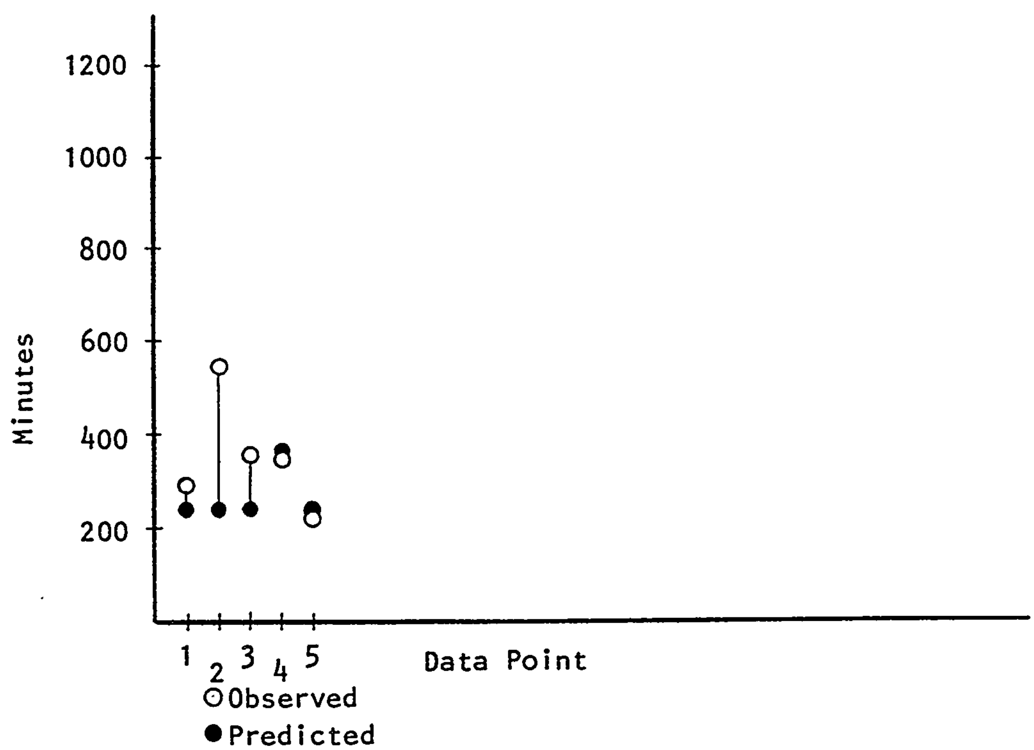
Time (ATOT) = 120.0*(Wld)

N = 5 (5 of 6 records in ISD data set 5 were usable)

Adj. R-sq. = 0.85

Point	WLD	ATOT observed	ATOT predicted	RESIDUAL
1	2	292.00	240.00	52.00
2	2	544.00	240.00	304.00
3	2	354.00	240.00	114.00
4	3	347.00	360.00	-13.00
5	2	219.00	240.00	-21.00
	TOTAL	1756.00	1320.00	

Prediction Error = 24.8%



For the ISD pipe shop, the results of testing the scheduling formulae are summarized in Table 12. **For the total observed work content of 3498 minutes falling within the limits of the formulae, the scheduling formulae predicted 3842.9 minutes, for a prediction error of 9.9%.** Even when using the aggregate formula, the prediction error was only 19.9%.

Table 12
Summary of Scheduling Formulae Testing

Formula	Observed	Predicted	% Error
1	6706.00	8041.59	19.9
2	6706.00	10809.31	61.2
4	1099.00	1701.00	54.8
5	495.00	653.00	31.9
6	148.00	168.90	14.1
7	1756.00	1320.00	24.8
Total (4+5+6+7)	3498.00	3842.90	9.9

4.6 Imported Standard Data Application and Testing

4.6.1 PBI Sheet Metal Fabrication

The standard data imported from NASSCO was applied to several shapes by means of the non-process factor developed for the PBI sheet metal fabrication shop. For each shape, performance data measured at PBI was broken down into the same attributes as needed to enter the NASSCO standard data listing, that is, light/small/large/short/etc. as defined by NASSCO. Several lines of PBI data could not be used and had to be rejected because the necessary attributes were missing. However, sufficient data remained to permit the assessment shown in Table 13, which compares times observed at PBI with the predicted times based on the imported NASSCO data.

Table 13
Summary of Predictions from Imported Standard Data

Shape	Notes	No. Fabs	Observ Minutes	Observ Min/Fab	Predict Minutes	Predict Min/Fab	Predict % Error	Min/Fab Error
1	1,2,3	49	2559	52	3263	66	27.5	+14
2	1,2,3	52	1959	38	1655	32	15.5	- 6
5	1,2,3	102	4970	49	6110	60	22.9	+11
6	1,2,3,4	31	743	24	742	24	0	0
8	1,2,4	5	254	51	295	59	16.1	+ 8
Total			10485		12065		15.1	

NOTES: 1 - light (< 1/16" thk)
2 - small (< 100 sq" opening)
3 - large (> 100 sq" opening)
4 - short (< 20" long)
Shape 1 - transition, rectangular to round
Shape 2 - rectangular transformer
Shape 5 - rectangular elbow
Shape 6 - straight duct
Shape 8 - offset

These results show, in general, that for the four manweeks of fabrication effort observed, the prediction capability was within about 15%. This degree of prediction accuracy is quite good, considering the small amount of effort needed to make it.

4.6.2 ISD Pipe Fabrication

Imported standard data application in the ISD pipe fabrication shop was not attempted by the Project Team because the necessary non-process factor information was not available. ISD did perform an internal analysis in this general area, but unfortunately information about this analysis arrived too late for evaluation by the Project Team and inclusion in this Final Report.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A. The application of imported classification-level standard data yielded predictions with an overall accuracy of about 15%. The predictions from the statistically developed scheduling formulae displayed an accuracy of about 10%. Either prediction method appears superior to present techniques.

B. The imported data approach was considerably quicker and easier to carry out than the statistical approach, although neither approach was excessively burdensome once it was set up and running.

C. Either approach requires the collection of performance data at the individual fabrication level. An ongoing program for data collection would therefore be needed for most satisfactory results.

D. The imported classification-level standard data approach appears sufficiently attractive that, whenever and wherever possible, the collection and exchange of classification-level standard data would be helpful to those shipyard personnel desiring to improve their prediction capability.

E. Knowledge of the information and techniques developed during performance of this Task would be helpful to those shipyard personnel desiring to try this approach to improving planning and shop loading in their production shops.

5.2 Recommendations

1. The techniques and findings developed during this Task should by promulgated to interested shipyard personnel via a series of regional workshops of one or two days duration.

2. A comprehensive system for performance data measurement, collection, and presentation should be developed in support of further effort in this general area.

3. A program for the identification, development, and distribution among interested shipyard personnel of classification-level standard data should be designed and promoted. This effort should include translation of the existing MOST database into classification-level standard data devoid of non-process components, if it is economically feasible to do so.

APPENDIX A

SYNOPSIS

OF

ENGINEERED LABOR STANDARD

INFORMATION

APPENDIX A

SYNOPSIS OF ENGINEERED LABOR STANDARD INFORMATION

This Appendix is a synopsis of information taken from the following references as it relates to the general subject of engineered labor standards, specifically formula standards developed from actual performance data from shipbuilding processes:

References

A - Bath Iron Works Corporation, A Manual on Planning and Production Control for Shipyard Use, September, 1978.

B - Bath Iron Works Corporation, Improved Planning and Production Control, August, 1977.

C - Bath Iron Works Corporation, Scheduling Standards Pilot Project: Summary Report, May 1982.

D - Graves and McGinnis, Inc., Scheduling Standards Pilot Project Companion Activity Final Report, June, 1982.

E - Bath Iron Works Corporation, Standard Data Application Guide, June, 1981.

F - Bath Iron Works Corporation, Labor Standards Classification System, January, 1982.

G - Bath Iron Works Corporation, A Primer on One Approach to Planning and Production Control for Shipyard Use, January, 1984.

H - Graves, R. J., McGinnis, L. F., and Robinson, R., "Standards for Production Planning and Control in Shipyard Shops," Proceedings of IREAPS Symposium, San Diego, September, 1982.

I - Graves, R. J. and McGinnis, L. F., "A Method for Establishing Useful Time Standards for Production Planning and Control in Shipyards," Proceedings of Symposium on Industrial Engineering Applications in Shipbuilding, Institute of Industrial Engineers Applications in Shipbuilding, Institute of Industrial Engineers National Conference, New Orleans, May, 1982.

1.0 HIERARCHY OF MANAGEMENT AIDS

It is recognized within the shipbuilding industrial engineering community that there is a hierarchy of engineered labor standards (Figure 1) which serves the management and planning function. This hierarchy is only briefly reviewed here, but more extensive descriptions may be found in References A, B, E, F, and G. The most detailed and lowest level of standard is the PROCESS STANDARD, the next highest level is the PRODUCTION STANDARD, then SCHEDULING STANDARD, PLANNING STANDARD, and finally the COST ESTIMATING STANDARD.

There are similarities among these levels in this standards family. Each is based upon a definition of the work method, upon an understood statement of the quality tolerances, and upon a degree of detail as determined by desired accuracy of results, by end use, and by the information available to the user. Yet, these standards will differ, largely as a result of this third factor.

A PROCESS STANDARD, designed to be used in detailed methods analysis by industrial engineers, is quite detailed in nature where fractions of seconds in time may differentiate one method from another and repetitive performance of the better method will result in significant time savings. By way of example, a SCHEDULING STANDARD is significantly different from the PROCESS STANDARD in several ways. Its use would typically be outside of the industrial engineering organization where schedulers and shop planners need to assess elapsed time for specific work packages to proceed through a shop (see Reference C). It provides a time budget on a work package where shipyard benefits accrue from better shop loading and schedule adherence rather than from specific methods improvement. The SCHEDULING STANDARD also reflects a non-repetitive situation where one package of work may significantly differ from another. A flexible means to determine the SCHEDULING STANDARD from the work content for time budgeting purposes makes it different from a PROCESS STANDARD. In this latter regard, the use of the word standard in SCHEDULING STANDARD is perhaps a misnomer because the SCHEDULING STANDARD actually consists of a collection of parameters and factors which, together with a systematic procedure, enable a scheduler to develop a work package time budget.

With this distinction in mind, it is possible to perceive of several ways by which to assist the scheduler in systematically utilizing those parameters and factors in determining a SCHEDULING STANDARD. One approach is that of using formulas. The formulas, with the proper parameters, weights, and assorted factors, are computed by the planner/scheduler after the specific attributes of the work are determined. Thus, the formula itself is the key to the systematic procedure. This flexibility of formula use for varying work attributes and content is what makes it an attractive approach for non-

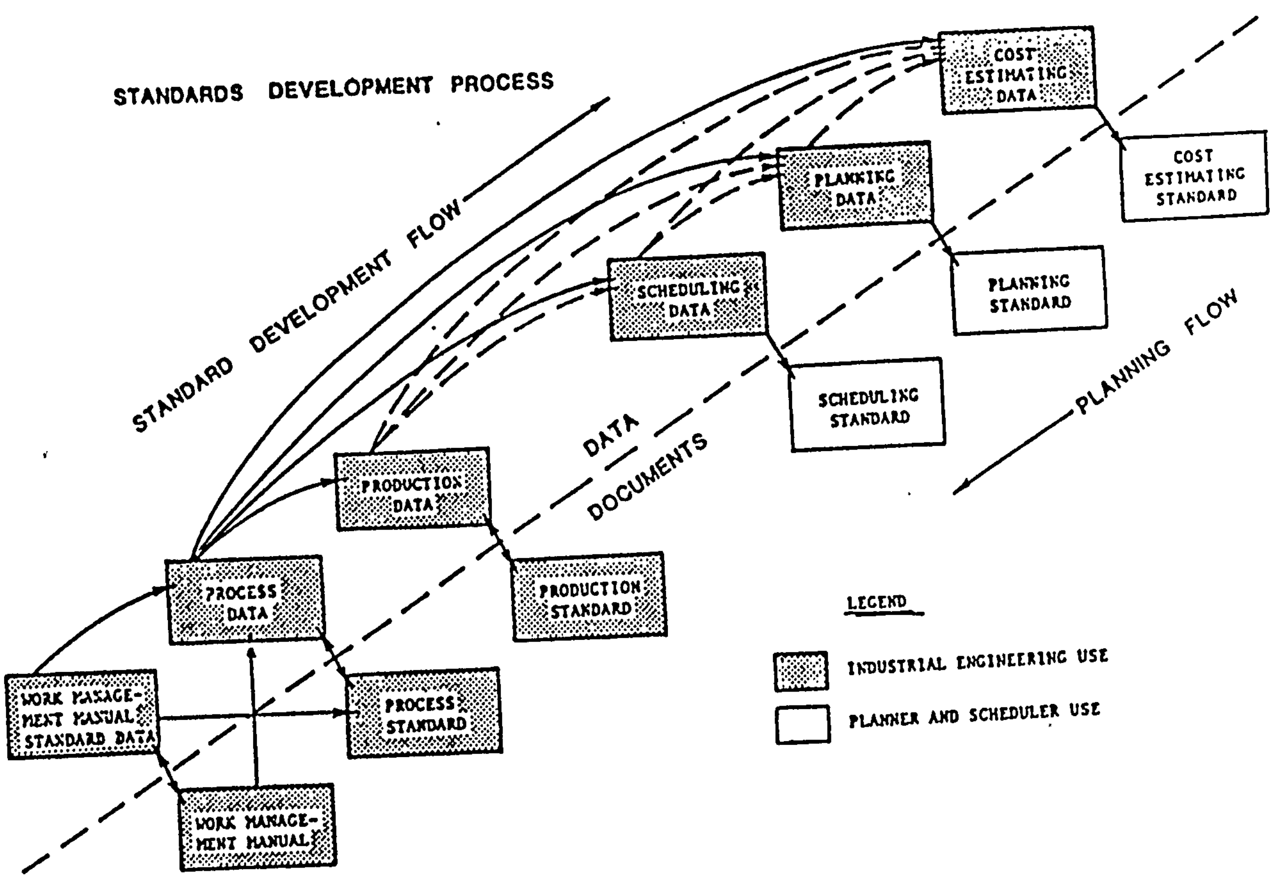

STANDARDS DEVELOPMENT PROCESS
STANDARD DEVELOPMENT FLOW
PLANNING FLOW
DATA
DOCUMENTS
COST ESTIMATING DATA
COST ESTIMATING STANDARD
PLANNING DATA
PLANNING STANDARD
SCHEDULING DATA
SCHEDULING STANDARD
PRODUCTION DATA
PRODUCTION STANDARD
PROCESS DATA
PROCESS STANDARD
WORK MANAGEMENT MANUAL STANDARD DATA
WORK MANAGEMENT MANUAL
LEGEND
INDUSTRIAL ENGINEERING USE
PLANNER AND SCHEDULER USE

FIGURE 1

repetitive work where it is impractical to establish standards on the basis of an individual time study for each job. Descriptions of formulas and how they might be used can be found in References D, H, and I. The following section provides a brief background on formulas and statistical methods for formula construction.

2.0 FORMULAS AND FORMULA CONSTRUCTION

An initial understanding of formulas in this context may be gained from the examination of a simplistic case where time, the dependent variable, is what one wants to predict based upon the values of some independent variable, perhaps inches of weld length. For reasons of assuring statistical confidence in this prediction, an experiment may be performed wherein a number of dependent variable values may be observed for a single value of the independent variable. Thus for a number of observations of weld times for a standard weld length of twelve inches on 1" steel plate, it is possible to examine the mean and distribution of the dependent variable, weld time, for a given specific value of the independent variable, weld length. As other specific values of the weld length (independent variable) are examined, the complete relationship between the two variables may be analyzed. The result of this analysis, in formula form, might be expressed as the following:

$$T = 1.2 + 0.3W$$

where T = mean time to weld (minutes)
W = inches of weld

When more than one independent variable affects time, both the formula and the analysis procedures which are used to determine the formula become more complex. An example of a more complex formula is drawn from the Scheduling Standards Pilot Project (References D, H, and I) where the time to fabricate a specific segment of a piping system might be determined by the following formula:

$$AT = 0.33 + 0.10 \times (DIA) + 0.45 \times (PCS) + 0.26 \times (BND)$$

where AT = time to fabricate
DIA = pipe diameter
PCS = number of pieces in the segment
BND = number of bends in the segment

Recalling that a SCHEDULING STANDARD requires the combining of PROCESS and/or PRODUCTION STANDARDS with other factors to develop a time budget for a package of work, suppose a formula approach for determining the work package time budget is used. For copper-nickel pipe, the dependent variable might be determined by the following formula:

$$AT = 0.43 \times ND + 1.21 \times ST$$

where AT = the work package time budget

ND = the number of pipe details drawings contained in the work package

ST = the standard time (i.e. combined PROCESS and PRODUCTION STANDARD time) to perform the isolated tasks

In this example, the two independent variables which determine the dependent variable are ND, the number of pipe detail drawings, and ST, the combined standard time to perform the isolated tasks. The value of ST may in turn derive from using engineered standard data within a shipyard, it may derive from a commercial standard data system such as MOST, or it may derive from data obtained by work sampling actual performance time. Since the goal of the SCHEDULING STANDARD is to improve schedule adherence by better prediction of work completion as well as better shop loading using this prediction, any of these sources for the value of ST may be beneficially used.

The PROCESS and PRODUCTION STANDARDS are directly related to the attributes of the work involved. Such attributes might include pipe material, pipe diameter, number and degree of bends, number and type of joint, number of couplers, and number of cuts. Thus a PRODUCTION STANDARD for a single pipe detail drawing would be obtained through a standard data system like MOST or CLASSIFICATION MOST by properly adding a column of numbers representing attribute/task times to reach a total time for the specified pipe detail. When determined for all pipe detail specifications in the work package, these PRODUCTION STANDARD times may be summed to obtain the value of ST.

It is also possible to relate the SCHEDULING STANDARD directly to the work attributes and thus bypass the time consuming task of collecting individual PROCESS and PRODUCTION STANDARD times in order to budget the work package time. As determined in the Scheduling Standards Pilot Project (References D, H, and I) the SCHEDULING STANDARD formula consolidates these PROCESS and PRODUCTION STANDARD times in the coefficients of the formula. Thus the calculated values of the coefficients will be highly dependent on the work mix used for the analysis. Such a formula for copper pipe details is as follows:

$$AT = 1.36 + 1.34 \times (DIA) + 0.25 \times (PCS) + 0.18 \times (JNT) + 0.62 \times (BND) + 0.08 \times (DxJ) - 0.08\,(DxP)$$

where AT = time budget
DIA = pipe diameter
PCS = number of pieces
JNT = number of joints
BND = number of bends
DxJ = diameter times number of joints
DxP = diameter times number of pieces

By extending the statistical analysis procedure used in formula construction, it is possible to determine proper ranges or limits for which either a single standard time or a single formula for calculating a standard time is appropriate. Sometimes the variables or formulas which predict time remain relatively constant within a specific group. Suppose shot blasting of metal plate may be classified by a single variable, area, as follows:

Group	Standard Time
Small (up to 300 square inches)	0.070 min.
Medium (300 to 750 square inches)	0.095 min.
Large (750 to 1800 square inches)	0.144 min.

This method of grouping means that plate area, as an independent variable, can range between two specific extremes (defines a group) and still provide for a single value of the dependent variable. If not performed with great care, this method of grouping will tend to give erroneous values for time at the extremes of each group, hence the problem is that of systematically determining the best specification of group extremes. It would usually be desirable to eliminate such groupings altogether and substitute a formula for the entire range of independent variable values. However, the tabular groupings approach may be viewed as less complex algebraically and thus easier to use in certain contexts. By scientifically determining the group boundaries, maximum retention of accuracy within this format should result.

APPENDIX B

ILLUSTRATIVE SAMPLE

OF

NASSCO SHEET METAL FABRICATION

STANDARD DATA

NORMAL TIMES

DUCT AREA
small <= 100 square inches
large > 100 square inches

DUCT MATERIAL
light <= 1/16
heavy > 1/16 AND < 3/16

SHAPES

S20 - Straight rectangular duct 20" long and below
- LIGHT
  - SMALL = 0.25 hours
  - LARGE = 0.29 hours
- HEAVY
  - SMALL = 0.37 hours
  - LARGE = 0.37 hours

S40 - Straight rectangular duct bet[illegible] long
- LIGHT
  - SMALL = 0.29 h[illegible]
  - LARGE = 0.3[illegible]
- HEAVY
  - SMALL = [illegible]
  - LARGE [illegible] hours

STR- [illegible]gular duct greater 40" long
- [illegible]
  - [illegible] = 0.40 hours
  - LARGE = 0.49 hours
- HEAVY
  - SMALL = 0.69 hours
  - LARGE = 0.69 hours

S_S - Square to square transformer less than 20" long
- LIGHT
  - SMALL = 0.29 hours
  - LARGE = 0.46 hours
- HEAVY
  - SMALL = 0.37 hours
  - LARGE = 0.37 hours

S-S - Square to square transformer greater than 20" long
- LIGHT
  - SMALL = 0.51 hours
  - LARGE = 0.55 hours
- HEAVY
  - SMALL = 0.54 hours
  - LARGE = 0.54 hours

APPENDIX C

ILLUSTRATIVE SAMPLE

OF

PBI SHEET METAL FABRICATION

PERFORMANCE DATA

The PBIDATA array is in 17 columns, as follows:

Column	Digits	Significance
1	nnn	Chronological serial number for the line of data.
2	cc	Shape of piece, coded as follows: (see bottom of data sheet) 01 - Transition, rectangular to round 02 - Rectangular transformer 03 - Transition, rectangular to rectangular 04 - Rectangular bellmouth 05 - Rectangular elbow 06 - Straight duct 07 - Round duct 08 - Offset 09 - Vane turn elbow 10 - Gored elbow 11 - Bellmouth 12 - Cone 13 - Acoustic square to round 14 - Elevation change fitting 15 - Acoustic elbow 16 - Acoustic change fitting 17 - Acoustic rectangular to round 18 - Acoustic duct 19 - Flat oval duct 20 - Diffuser box 21 - Reducer cone
3	cc	Material composition, coded as follows: 01 - Galvanized steel 02 - Perforated aluminum 03 - Stainless steel
4	mmm	Gauge of material
5	c	Seam type, coded as follows: 1 - Pittsburgh 2 - Rivet 3 - Lock 4 - Weld 5 - 3/4" lap 6 - Spot weld 7 - Spot weld and rivet 8 - Lap 9 - Lockform
6	mmm	Time, in minutes
7	ll.ll	1st opening height, in inches
8	ll.ll	1st opening width, in inches
9	ll.ll	2nd opening height, in inches

10	ll.ll	2nd opening width, in inches
11	dd.dd	Diameter, in inches
12	dd.d	Angle, in degrees
13	ll.ll	1st length, in inches
14	ll.ll	2nd length, in inches
15	ll.ll	Offset, in inches
16	nn	Number of pieces. One piece is assumed, unless an entry appears.
17	cc	Joining method, coded as follows: 01 - Slip & Drive (S&D) 02 - S&D + Flange 03 - Flange RTR Flange 04 - Flange 05 - Flange + S&D 06 - Lock 07 - Rivet 08 - Weld 09 - Flange + S&R 10 - S&R 11 - Pittsburgh 12 - Flange + Rivet 13 - Bolt 14 - Spot weld 15 - Flange + Weld 16 - Pittsburgh + Rivet 17 - Pittsburgh + Bolt 18 - Pittsgurgh + S&D 19 - Spot weld + S&D

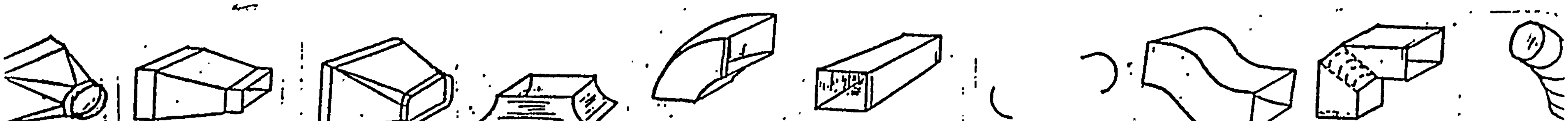
12/5

SHEETMETAL TIME REPORTING SHEET

(Individual Piece Fabrication Only)
(To Be Turned in Daily to Foreman)

PIECE I.D.#	DESCRIPTION OF PIECE	DIME... OF P...	TYPE & GAUGE OF MATERIAL	SEAM TYPE	START	STOP	JOINING METHOD
8	OFFSET	5x8 To ...	24GA SS	Pitt	6:45	8.30	
5	REC ELBOW	8x4 x 8x	24 SS	Pitt	9:30	10:00	
5	REC ELBOW	8x4 x 8x4	24 SS	Pitt	10.00	11:00	
5		10x6 to 10x6	...4ga ss	PITT	12:25	1:00	
5	"	10x6 To 10x6	...ga SS	Pitt	1:00	1:45	
5	REC, OFFSETTING 90° ELBOW	8x5 to 6x5	... SS	"	1:45-3:15	3:45-8:00	
5	REC. ELBOW	4x8	... SS	"	8:00	9:00	
8	Rec. OFFSET	3½x6½	... ...	"	10:00	11:50	
2	REC TRANSFORMER	7½x12x12x12	22	"	6:45	8:00	
5	REC ELBOW	11x5x11x5	22...	"	8:00	9:30	
3	TRANSITION	8x14x15x4	22G	"	9:30	10:30	
3	TRANSITION	15x4 To 11x5	22G	"			

ILLUSTRATIVE SAMPLE ONLY
NOT ACTUAL NUMBERS



1 - TRANSITION   2 - REC. TRANSFORMER   3 - TRANSITION   4 - REC. BELLMOUTH   5 - REC. ELBOW   6 - STRAIGHT DUCT   7 - R...   8 - OFFSET   9 - VANE TURN ELBOW   10 - CORE...

Any questions contact Dan Kressig @404.

11 - OTHER (DESCRIBE)

SER	SHA CDE	MAT CDE	GAU	SEM CDE	MIN	HGT No1	WDH No1	HGT No2	WDH No2	DIA IN	ANG DEG	LGH No1	LGH No2	OFF SET	NUM PCS	JNG CDE
115	6	3	26	1	15	7.00	7.00					12.00				1
116	6	3	26	1	12	7.00	3.00					11.50				5
117	1	3	26	6	56	6.00	3.00			3.00					2	14
118	6	3	26	1	16	7.00	4.00					25.00				5
119	6	3	26	1	17	7.00	7.00					22.00				2
120	1	3	26	6	36	6.00	3.00			3.00						14
121	1	3	26	6	60	5.00	1.00			3.00						14
122	1	3	22	6	45	14.00	4.00			4.40						14
123	5	3	24	9	30	7.75	6.00				90					1
124	5	x	20	9	45	18.00	6.00				90					
125	5	1	20	9	90	13.00	4.00				90					
126	5	x	20	3	45	18.00	6.00				90					
127	5	1	20	3	60	15.50	6.00				90					
128	3	x	20	8	20	18.00	6.00	4.00	6.00			x				
129	1	x	22	8	15	2.50	6.00			4.50						7
130	8	x	22	3	15	7.75	6.00					x				11
131	2	x	22	3	30	8.00	6.00	10.50	6.00							11
132	5	x	20	3	30	6.00	18.00				90					11
133	7	3	22	6	40					6.00						14
134	7	3	22	6	24					4.00						14
135	4	3	22	3	90	15.00	6.00	10.50	6.00							17
136	4	x	22	3	90	12.00	6.00	7.50	6.00							17
137	2	1	22	3	30	7.50	6.00	10.00	6.00							11
138	1	1	18	3	30	18.00	6.00									11
139	1	1	22	3	15	7.75	6.00									11
140	1	x	24	8	20	2.50	6.00									7
141	5	x	22	3	30	10.00	6.00				60					11
142	8	x	20	4	30	7.50	6.00					x		x		8
143	3	3	22	3	30	7.75	6.00					x				11
144	1	3	12	4	37	12.00	6			6.00					2	8
145	1	3	16	4	45	3.50				5.00						8
146	1	3	16	4	73	4.5				6.00						8
147	5	3	22	1	15	10					90					5
148	8	3	24	1	53							14.00		x		1
149	5	3	24	1	5						90	15.00				1
150	5	3	24	1			.00				90	13.00				5
151	8	x	24	1			3.50					30.00		x		5
152	5	3	24			0	5.50				90	17.00				1
153	5	3	2			.00	5.50				90	22.50				1
154	8	3				10.50	3.00					26.00		x		1
165	2				27	3.00	10.50	x	x			8.00				1
156					38	14.00	8.00				90			x		4
157				1	75	8.00	6.25	10.00	6.25			26.00		13.00		1
				1	45	7.75	8.00	12.00	6.00			x		x		1
			22	1	30	11.00	10.00	14.00	8.00			13.00				1
		3	22	1	40	3.50	6.00	10.00	10.00			16.00				1
		3	20	1	45	10.00	5.50	23.25	10.50			16.00				1
	5	3	20	1	50	23.00	12.00				30					1
	2	3	20	1	60	23.25	10.50	6.25	10.50			16.00				1
164	5	3	22	1	50	12.00	5.00				90	11.00				2
165	5	3	20	1	40	23.00	12.00				30					2
166	3	3	20	1	60	10.00	7.00	x	x			16.00				1
167	5	3	20	1	45	12.00	23.00				90					1
168	5	3	20	1	55	12.00	23.00				90					1
169	2	3	20	1	45	5.00	12.00	23.25	10.50			16.00				1
170	5	3	20	1	45	23.00	12.00				90	9.00				11
171	5	3	20	1	40	21.00	10.00				90	18.00				11

APPENDIX D

ILLUSTRATIVE SAMPLE

OF

ISD PIPE FABRICATION

PERFORMANCE DATA

ISDDATA

DEFINITIONS

The **ISDDATA** file is in 21 columns, as follows:

Column

- A - Chronological serial number traceable to the ISD data and sketches
- B - Material code, defined as follows:
  - 0 - Material not specified in data received from ISD.
  - 1 - Copper nickel alloy - 90-10
  - 2 - Copper
  - 3 - CRES
  - 4 - Carbon steel
  - 5 - Aluminum alloy (i.e. ANSI B16.9, 5086, WW-T-70015 Ty 1)
  - 6 - Copper nickel alloy - 70-30
- C - Diameter, in inches
- D - Total number of welded joints (this entry is the sum of EFGHI)
- E - Number of butt welds
- F - Number of flange welds
- G - Number of socket welds
- H - Number of weld o'lets
- I - Number of tack welds
- J - Total number of silbraze joints (this entry is the sum of KLM)
- K - Number of silbraze connections (other than LM)
- L - Number of silbraze flange connections
- M - Number of silbraze o'lets
- N - Total number of mechanical connections (this entry is the sum of OPQ)
- O - Number of flange-to-valve connections
- P - Number of screwed connections
- Q - Number of drilled holes
- R - Actual fit time in minutes
- S - Actual weld time in minutes
- T - Actual "other" time in minutes
- U - Total Actual time in minutes (this entry is the sum of RST)

ER	MAT	DIA	TOT WLD	BW	FLG	SW	O LET	TK	TOT BRZ	SB	SB FLG	O LET	TOT MEC	FLG VLV	SCR CON	DRL HLE	ACT FIT	ACT WLD	ACT OTH	ACT TOT
80	1	3.00	6	4	2				0				0				258			
31	0	3.00	0						0				0				312			
82	6	10.00	3					3	0				0				192			
33	6	10.00	3					3	0				0				180			
84	4	6.00	4	3				1	0				0				378			
35	3	1.00	4			4			0				0				198			
86	1	6.00	6	6					0				0				456			
87	0	4.00	3	3					0				0				222			
88	4	3.00	4	3				1	0				0				108			
89	4	4.00	1	1					0				0				360			
	4	3.00	8	8					0				0							
	4	1.00	1					1	0				0							
	4	0.25	1					1	0				0							
90	4	4.00	7	5				2	0				0				330			
91	4	4.00	4	2				2	0				0							
92	1	3.00	1	1					1		1		0							138
93	2	6.00	0						2	2			0							102
	2	1.00	0						1			1	0							
94	2	6.00	0						3	2	1		0							72
95	2	6.00	0						3	3			0							132
96	2	3.00	0						6	4	2		0				288			288
	2	1.25	0						8	8										
97	2	2.50	1			1			3	1	2						240	30	30	300
98	5	4.00	3	2	1				0								192	96	12	300
99	5	4.00	1	1					0								96	96	12	204
00	5	4.00	1	1					0								150	102	12	264
01	2	2.00	0						1								78	30	12	120
02	1	4.00	1	1									0				180	84		264
	1	2.50	2	1	1								0							
03	6	2.00	2	2									6			6	348	60		408
04	1	2.50	6	2	4								4	4			420	36		456
	1	1.00	1	1									0							
105	1	1.00	0							16	2		1	1			420	36		456
106	4	2.00	5	2	1				0				0				300	186		486
	4	0.50	3						0				0							
107	4	8.00	7						0				0				180	120		300
108	4	4.00	4					2	0				0				60	30		90
109	4	6.00							0				0				120	60		180
110	1	2.50							9	6	3		5	5			720	30		750
111	2	3							1	1			0				1440	30		1470
	2								7	5	2		2	2						
									9	7	2		2	2						
									7	7			7		7					
			6	4		2			0				0				840	60		900
			5	3		2			0				3	3						
		.50	0						11	10	1		0							
		2.50	3	3					1	1			0				240	30		270
	1	6.00	1		1				0				0				18	30		48
	1	4.00	1		1				0				0							
115	4	2.00	7		1	6			0				1	1			480	192		672
116	4	2.00	6			6			0				0				180	144		324
117	4	6.00	5	4	1				0				0				120	120		240
118	4	2.00	8			8			0				0				480	216		696
	4	0.50	1				1		0				0							
119	4	2.50	6	4		2			0				0				240	228		468

ILLUSTRATIVE SAMPLE ONLY
NOT ACTUAL NUMBERS

APPENDIX E

ILLUSTRATIVE SAMPLE

OF

PBI PIPE FABRICATION

STANDARD DATA

FABRICATION STANDARDS

Carbon and Stainless Steel Standards

DIAMETER	PER: JOINT, SLEEVE, VALVE*	FLANGES*	"O" LETS, BOSSES	CUT OR THREAD ONLY
1/2"	12	15	31	12
3/4"	12	18	32	12
1"	15	21	34	12
1¼"	16	23	36	
1½"	17	25	37	
2"	18	27		12
2½"	19			14
3"	20		--	14
3½"		30	--	14
4"		53	--	16
	47	55	--	16
	55	64	--	16
8"	69	72	--	16
10"	79	82	--	16

*Times do not include welding.